NETL Accomplishments

2013

U.S. DEPARTMENT OF ENERGY | the ENERGY lab
NATIONAL ENERGY TECHNOLOGY LABORATORY

Mission

Advancing energy options to fuel our economy, strengthen our security, and improve our environment.

2013

Contents

INTRODUCTION

2013—Another busy year here at the Energy Department's National Energy Technology Laboratory (NETL)! Scientists, engineers, and analysts at NETL continued working to deliver the innovative and transformative scientific and technological solutions to energy security and the economic and environmental challenges facing the United States. Whether conducting original research—or managing research projects conducted by academia, industrial partners, or other national labs—our overarching goal was, as always, to transfer technology, knowledge, and expertise to markets that serve the American people.

This report provides a sampling of NETL's accomplishments in 2013, organized into six broad categories:

- *Carbon Management*
- *Water & Energy*
- *Advanced Power Systems*
- *Reliable Supply*
- *Science & Technology Leadership*
- *Awards*

Under each of these headings are articles describing a wide range of advances made by NETL during 2013. You'll find descriptions of more efficient gas turbine rotor blades, plastics made from recycled carbon dioxide (CO_2), potable water produced by gas hydrates, a discovery that may make blood sugar testing painless, and much more.

As the research arm of the U.S. Department of Energy's (DOE) Office of Fossil Energy, NETL's efforts often focus on fossil energy, our most abundant domestic energy resource—but we don't stop here. The laboratory also conducts work for DOE's Office of Electricity Delivery and Energy Reliability and DOE's Office of Energy Efficiency and Renewable Energy. In 2013, through these projects, NETL played a part in introducing a new lighting innovation, showcasing an award-winning battery storage project, and developing many other revolutionary technologies.

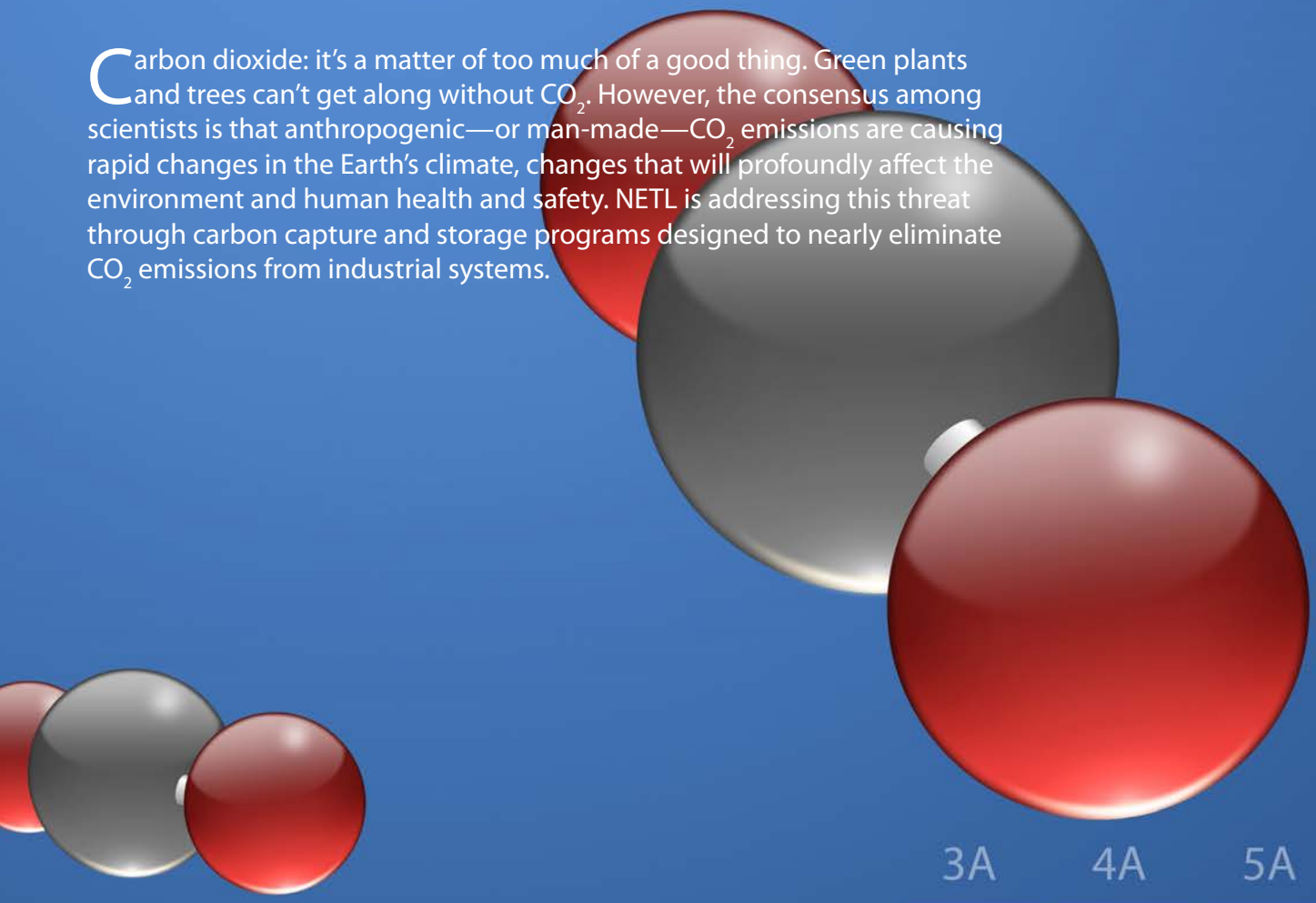
Surmounting challenges is what NETL is all about. We are proud of the accomplishments we realized in 2013 and our contribution to ensuring our nation's economic security, energy independence, and environmental safety. We look forward to a dynamic and rewarding 2014, serving the United States through the development of innovative ideas, capabilities, and products.

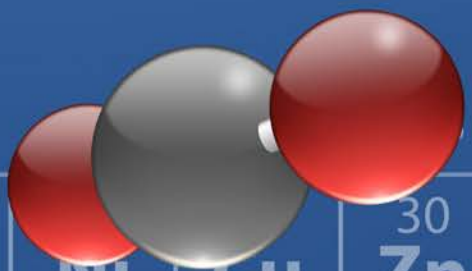
LiBOB

LiODFB

Carbon Management

Carbon dioxide: it's a matter of too much of a good thing. Green plants and trees can't get along without CO_2. However, the consensus among scientists is that anthropogenic—or man-made—CO_2 emissions are causing rapid changes in the Earth's climate, changes that will profoundly affect the environment and human health and safety. NETL is addressing this threat through carbon capture and storage programs designed to nearly eliminate CO_2 emissions from industrial systems.





3A	4A	5A	6A
5 **B** $[He]2s^2 2p^1$ boron **10.81**	6 **C** $[He]2s^2 2p^2$ carbon **12.01**	7 **N** $[He]2s^2 2p^3$ nitrogen **14.01**	8 **O** $[He]2s^2 2p^4$ oxygen **16.00**
13 **Al** $[Ne]3s^2 3p^1$ aluminum **26.98**	14 **Si** $[Ne]3s^2 3p^2$ silicon **28.09**	15 **P** $[Ne]3s^2 3p^3$ phosphorus **30.97**	16 **S** $[Ne]3s^2 3p^4$ sulfur **32.07**

7B	8B							
25 **Mn** $[Ar]4s^2 3d^5$ manganese **54.94**	26 **Fe** $[Ar]4s^2 3d^6$ iron **55.85**	27 **Co** $[Ar]4s^2 3d^7$ cobalt **58.93**	**Ni** $[Ar]4s^2 3d^8$ nickel **58.69**	**Cu** $[Ar]4s^1 3d^{10}$ copper **63.55**	30 **Zn** $[Ar]4s^2 3d^{10}$ zinc **65.39**	31 **Ga** $[Ar]4s^2 3d^{10} 4p^1$ gallium **69.72**	32 **Ge** $[Ar]4s^2 3d^{10} 4p^2$ germanium **72.58**	33 **As** $[Ar]4s^2 3d^{10} 4p^3$ arsenic **74.92**	34 **Se** $[Ar]4s^2 3d^{10} 4p^4$ selenium **78.96**
43 **Tc**	44 **Ru**	45 **Rh**	46 **Pd**	47 **Ag**	48 **Cd**	49 **In**	50 **Sn**	51 **Sb**	52 **Te**

Researcher Hanjing Tian displays an oxygen carrier developed by NETL for chemical looping combustion.

Waste CO_2 makes up over 40 percent by weight of this new polymer.

Oxygen Carriers Bring Chemical Looping Another Step Closer to Commercialization—NexTech Materials of Lewis Center, OH, has successfully prepared commercial-scale batches of two NETL-developed oxygen carriers for use in chemical looping combustion: a magnesium oxide-promoted natural mineral hematite oxygen carrier and a synthetic carrier consisting of copper oxide, iron oxide, and alumina. Both offer increased service life and high stability through many combustion cycles. Such advancements significantly boost the economics of chemical looping combustion, positioning it to be a highly effective carbon management tool for electric power generation.

In the hematite-based carrier, NETL researchers discovered that incorporating magnesium oxide into natural hematite strongly modifies reduction activity compared to using either material alone. By combining the materials, NETL doubled the hematite's oxygen transfer capacity and increased the reaction rate fivefold. In the synthetic carrier, researchers observed significantly better performance versus natural mineral-based carriers.

NETL researchers teamed with NexTech to scale up the laboratory procedure for preparing these successful formulations. The resulting 400-pound batch of each oxygen carrier will undergo fluidized bed tests in NETL's pilot-scale 50-kilowatt-thermal chemical looping unit. U.S. patent applications have been submitted for these new oxygen carriers.

Recycling CO_2 To Make Plastics—Converting captured CO_2 into products such as chemicals, plastics, fuels, building materials, and other commodities is an important component of the Office of Fossil Energy's Carbon Capture and Storage Program. As part of an NETL-managed project under the program, sustainable chemistry company Novomer and its partner Albemarle Corporation have created polycarbonate polymers that contain more than 40 percent waste CO_2 by weight.

Conventional production of plastics depends heavily on fossil fuels as feedstock, but the Novomer process reduces their use by replacing up to half the mass of the petroleum-based product with CO_2. The polymers can then be tailored to create a broad range of materials, from solid plastics to soft, flexible foams to viscous liquids, depending on the size of the polymer chain. Novomer is positioning its new polymer technology to compete with conventional petroleum-based raw materials across a diverse range of applications, including thermoplastics, adhesives and sealants, and coating resins for food and beverage cans.

What is chemical looping combustion?

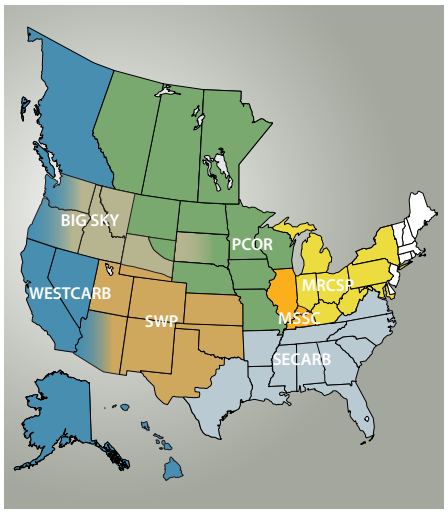
It's a promising option for power generation without CO_2 emissions. Chemical looping is a flameless process in which there is no direct contact between air and fuel. It relies instead on chemical "carriers" to provide the oxygen needed for fuel combustion.

Did you know?

Chemical looping provides many advantages over traditional combustion: it emits no nitrogen oxide, it creates a concentrated CO_2 stream ready for capture, and it incurs no energy penalty or reduction in power plant efficiency for CO_2 separation.

This modular membrane skid was installed at the National Carbon Capture Center to demonstrate a CO_2-separation system based on MTR's Polaris membrane. (Image courtesy of MTR)

The blue spark shown in this photo is generated by a high-intensity laser pulse. This portable technology was developed to monitor CO_2 stored underground.



The seven NETL-managed Regional Carbon Sequestration Partnerships are Big Sky, PCOR, MGSC, MRCSP, SECARB, SWP, and WESTCARB.

MTR Demonstrates CO_2 Removal System for Gasification Plants—Membrane Technology and Research, Inc., (MTR) demonstrated a CO_2 separation and capture system developed using its Polaris membrane. Common CO_2 absorption systems used in gasification plants are large, complex, and energy intensive. The Polaris membrane system operates efficiently at the high temperatures required in gasification plants and can lower the energy required for synthesis gas (syngas) cleanup.

To test the Polaris system, MTR and the National Carbon Capture Center fed a slipstream of syngas into a coal gasifier module for 500 continuous hours. The system successfully separated CO_2 from this slipstream, processing 500 pounds of syngas per hour and producing liquid CO_2. Capturing CO_2 in liquid form saves the energy associated with compressing the gas prior to use or storage. If the Polaris system proves viable at commercial scale, it could reduce the operational costs of coal gasification for power production and carbon capture and help broaden the application of this clean, reliable coal-processing technology.

Compact Sensor Technology Monitors Stored CO_2—Capturing and storing CO_2 in geologic formations is a process that can mitigate CO_2 emissions and protect our environment. As carbon storage technologies are implemented, reliable monitoring efforts must be undertaken to ensure that wells are structurally sound and stored CO_2 remains within the injection formation.

A team of researchers led by NETL has developed an optical sensor for CO_2 storage and leak monitoring based on laser-induced breakdown spectroscopy, or LIBS. The LIBS sensor employs a laser-generated plasma spark to detect CO_2 leaks in the field, underground, or under water. The LIBS system, which is compact and portable, can also be used for environmental research related to natural gas production from Marcellus shale. NETL has submitted a patent application for the LIBS technology.

Dynamic Partnerships Celebrate a Decade of Carbon Storage Study—For 10 years, NETL has managed the Regional Carbon Sequestration Partnerships (RCSP) Initiative—the lead U.S. program investigating methods for successfully storing CO_2 in geologic formations. The International Energy Agency calls the RCSP a "world-leading program for CO_2 storage research and public outreach."

More than 400 government, industry, academic, and nonprofit organizations in 43 states and 4 Canadian provinces make up the RCSPs. They represent seven unique regions throughout the United States and Canada that feature a wide range of emission sources, climate, topography, geology, population density, and socioeconomic development. The three RCSP Initiative phases include small- and large-scale field projects associated with carbon storage. Phases I and II are complete, and Phase III is under way.

In Phase I, *characterization*, the partnerships located CO_2 sources and characterized and assessed suitable CO_2 storage locations in deep oil,

natural gas, coal, and saline-bearing formations. This phase served as the foundation for the initiative and resulted in the publication of the National Carbon Sequestration Database and Geographic Information System (NATCARB) and the first *Carbon Storage Atlas*, which provide CO_2 emissions and storage capacity data for North America and updates on RCSP Initiative projects.

In Phase II, *validation*, the RCSPs built on the work conducted through Phase I by completing 19 small-scale field projects in various storage formations at different depths to validate their capability to safely store and monitor CO_2. Field projects confirmed storage estimates and injection capability; validated reservoir simulation models; demonstrated effective monitoring, verification, and accounting methods; and informed guidelines for well completion, operation, and closure.

Phase III, *development*, builds on the success of Phase II results and focuses on large-scale (1 million metric ton) field projects. Currently, eight large-scale geologic storage research field projects are demonstrating the long-term, effective, and safe storage of CO_2 in major geologic formations throughout the United States and portions of Canada. More than 5 million metric tons of CO_2 have already been injected at 6 different field sites. After injections are completed, the RCSPs will monitor and verify the continued containment of CO_2 in the target formations.

Each RCSP hosts a website with information about its projects and how they relate to CO_2 storage within the partnership's geographic area. In addition, the RCSPs continue to contribute to a series of best practices manuals that are capturing lessons learned throughout the initiative.

Other sources for information about the RCSPs include NATCARB and the most recent atlas, *The 2012 United States Carbon Utilization and Storage Atlas*.

RCSP Accomplishments—10 Years of Success

Technical Achievements

In Phase I, characterization of the storage potential of various rock types and geologic settings led to site selections for injection projects in the Phase II validation process. In Phase II, 19 small-scale field projects were completed, storing more than 1 million metric tons of CO_2 and validating technologies for geologic storage, simulation and risk assessment, and monitoring and verification. The resulting data provided a basis for Phase III—large-scale development projects.

As of late 2013, eight Phase III field projects are planned for the initiative. Cumulatively, they will inject 9 million metric tons of CO_2 and validate carbon storage technologies that can be commercially deployed. These projects will be key to the future deployment of carbon storage as a viable technological solution to mitigate greenhouse gas emissions.

Knowledge Transfer

The RCSPs interact with national and international organizations to advance carbon capture and storage technologies worldwide. These organizations include the International Energy Agency, the Global Carbon Capture and Storage Institute, the Carbon Sequestration Leadership Forum, the North American Carbon Atlas Partnership, and the U.S.-China Clean Energy Research Center.

The partnerships have produced an extensive body of work, including seven best practices manuals; four editions of the United States Carbon Utilization and Storage Atlas; NATCARB; the Carbon Capture and Storage Database; and contributions to NETL's Energy Data eXchange.

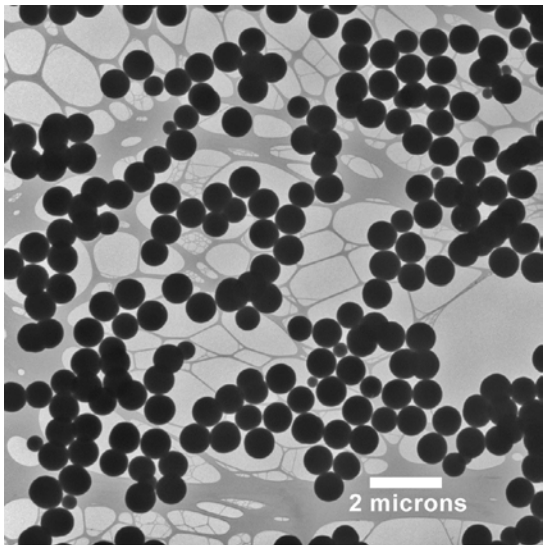
Public Outreach

Throughout the three phases, the RCSPs have engaged in ongoing conversations with local communities, scientific organizations, government agencies, and other groups to inform the public about carbon capture and storage. Activities include open houses, public forums, workshops, stakeholder discussions, technical contributions to public documentation, and educational outreach.

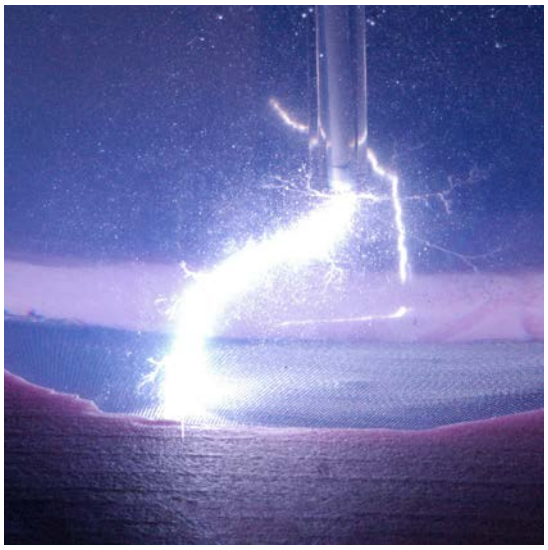
Public outreach products have included websites, articles, regional atlases, a carbon capture and storage training center, and a five-DVD series on carbon capture and storage.

Water & Energy

For years to come, our nation is expected to need power produced by fossil fuels. Water is inherent to fossil-based energy production—from drilling for natural gas and oil to operating thermoelectric steam turbines. However, clean water is a limited resource needed alike by communities, agriculture, the natural environment, and power producers. How can we reclaim and reuse impaired and produced water associated with drilling operations? How can we reduce water use in power plants? NETL is working to find answers to these and other water–energy related questions.



Silica particles like the ones in this micrograph can be adsorbed by a new aluminum oxide material developed by GE Global Research, making impaired water suitable for use in power plant cooling towers.



A pulsing spark discharged into the cooling water of a coal-fired power plant can prevent scale buildup and reduce water use in the plant.

Novel Material Makes Impaired Water Suitable for Power Plant Cooling—Thermoelectric power generation requires water to produce steam—and to cool it after it has passed through the turbine system. Using impaired waters for cooling is one way to reduce the freshwater withdrawal normally required by coal-fired power plants. This will help operators meet growing electricity demands without further stressing community water supplies.

The problem is that although some reclamation techniques remove unwanted dissolved salts from impaired waters, they leave behind high concentrations of scale-forming silica that can cause significant problems in power plant cooling towers.

As part of the Power Plant Water Program portfolio managed by NETL, investigators at GE Global Research (Nishkayuna, NY) have developed a new aluminum oxide material that, per gram, adsorbs 0.11 grams of silica from water. In laboratory-scale tests, the material removed enough dissolved silica from impaired water to make it acceptable for reuse in thermoelectric power systems. To make the process more efficient, the team also developed a low-cost regeneration process that recycles the material multiple times with minimal loss in activity.

Treatment Method Reduces Water Consumption by Power Generators—Researchers at Drexel University (Philadelphia, PA) have devised and demonstrated a bench-scale prototype plasma water treatment method designed to minimize performance-degrading scaling on power plant steam condenser tubing. The scaling, which inhibits heat transfer, is caused by the buildup of minerals, such as calcium and magnesium, in recirculating cooling water systems as water evaporates in the cooling towers. Power plants may use 10 million gallons of water each day, a majority of which is used to prevent this scaling. Drexel's plasma treatment method could reduce a typical 1,000 megawatt fossil-fueled power plant's freshwater consumption by approximately 25 percent.

The Drexel technology, developed under the Power Plant Water Program managed by NETL, employs a pair of electrodes immersed in the recirculating water to discharge a high-voltage spark every 10–50 nanoseconds. The low-energy pulsating electric field allows calcium and magnesium to precipitate as solids that can then be mechanically filtered from the water upstream of the condenser.

Did you know?

"Impaired waters" are those that are too polluted or otherwise degraded to meet water quality standards. "Produced water" is a specific byproduct of oil and gas production that is considered industrial waste. Both impaired and produced water can be cleaned and reclaimed for use in power plants in place of freshwater supplies.

feature article

Northern Great Plains Water Consortium Project Addresses Water-Energy Nexus

Thermoelectric power plants require large volumes of water to operate. A new supercritical thermoelectric unit reduces the amount of water needed for every megawatt-hour of energy produced.

Water and energy are intricately linked. Understanding the relationship between them is fundamental to determining how to make the most efficient use of these critical resources, both for short-term economic benefit and for longer-term societal and environmental sustainability.

To better understand the dynamics of the link between water and energy, the Northern Great Plains Water Consortium (NGPWC) was established. NGPWC is a partnership between the University of North Dakota Energy & Environmental Research Center, NETL, and key stakeholders in the Great Plains region, including electric power generating utilities, oil and gas companies, industries, municipalities, and state agencies. The 5-year partnership addresses issues related to water availability, reducing water usage, and minimizing the environmental impacts of electricity-generating facilities on water quality.

As the U.S. population and associated economic development continues to expand, the demand for electricity will increase. For the foreseeable future, thermoelectric generation of power from coal, natural gas, oil, and nuclear sources will continue to be the primary sources of electricity in the United States and around the world. But thermoelectric power plants require large volumes of water to operate. In fact, according to the U.S. Geological Survey, thermoelectric generation accounts for approximately 40 percent of all freshwater withdrawals in the United States. These plants primarily use water to cool down (condense) steam after it has been used to turn a steam turbine to generate power.

A majority (approximately 96 percent) of the withdrawn water is returned to surface water supplies where it becomes available for other uses. While only a small percentage of water is actually consumed, thermoelectric power plants withdraw approximately 143 billion gallons of freshwater per day from rivers, lakes, streams, and aquifers. Withdrawing such large quantities of water directly competes with other sectors, such as irrigation, and becomes especially problematic in water-constrained regions.

As a result of the strategic NGPWC partnership, significant advances have been made in the understanding and management of water-related issues relative to energy production. These results will help satisfy competing water demands arising from multiple industries in the northern Great Plains region. The establishment of a scientifically sound and unbiased approach to water management issues will prove instrumental in making management and regulatory decisions related to water use.

The NGPWC partners set out to achieve the following key goals: (1) identify innovative solutions to expand water resource options for

energy producers; (2) evaluate water demand and consumption from competing users in the northern Great Plains region, including energy production, agriculture, industry, and domestic and municipal users; (3) assess, develop, and demonstrate technologies and methodologies that minimize water use and reduce wastewater discharge from energy production and agricultural processing facilities; and (4) identify nontraditional water supply sources and novel options for water reuse.

The NGPWC's results culminated in the successful completion of eight separate research projects. Here are some of their specific research accomplishments:

- Investigated water supply and disposal issues in the Bakken shale oil play, where the research team successfully demonstrated how reverse osmosis can be economically employed to treat non-potable saline groundwater for reuse as makeup water for hydraulic fracturing (fracking).

- Identified the potential to recover up to 200,000 gallons per day of high-quality water from Great River Energy's lignite fuel enhancement system by using a commercial ambient air heat exchange process that is marketed by SPX Cooling Technologies as ClearSky™ technology.

- Identified water supply and use issues related to existing and planned coal-fired power generation facilities in the NGPWC region. The research team compiled data and information on surface water resources, groundwater resources, and municipal and industrial wastewater treatment plant discharges for the NGPWC's Water Resource Decision Support System.

- Developed a half-hour documentary on the water-energy nexus, "Water: The Lifeblood of Energy."

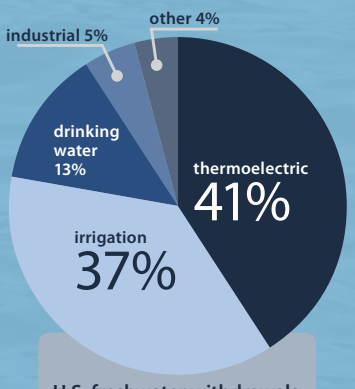
- Examined water usage for carbon capture during post- and oxyfuel-combustion systems.

- Investigated energy-saving opportunities for water treatment, including ozonation and ultra-violet disinfection processes and found ozonation to be the most cost-effective.

- Demonstrated key operating concepts of a dry cooling alternative for power plants that led to successful process development and a laboratory-scale performance demonstration.

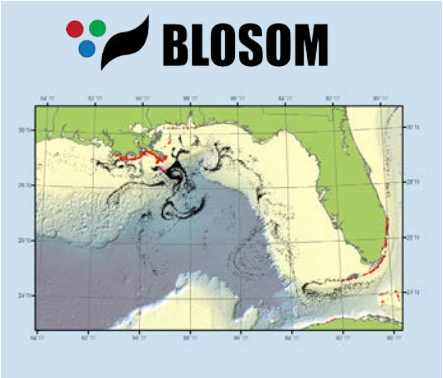
- Studied water supply and treatment issues faced by oil refineries that are processing lower-cost crude oils and heavier feedstocks containing higher levels of sulfur, selenium, and heavy metals. The team identified instrumentation needs and approaches to control these components—components that can also produce hazardous air pollutant emissions—and completed a review of the economics related to wastewater issues.

The water-energy nexus defines the many relationships between energy and water that are necessary to ensure an adequate, sustainable supply of both resources for multiple purposes. Because thermoelectric power generation and fossil fuel extraction impact water resources, it is critically important to protect water supplies while also providing the energy needed to power our nation.

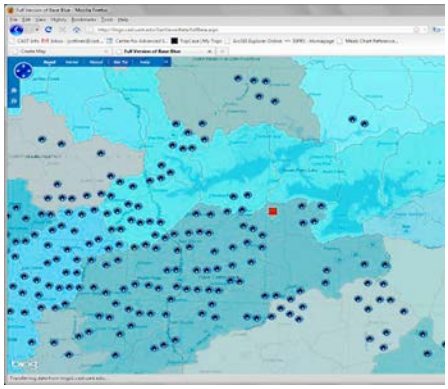


U.S. freshwater withdrawals

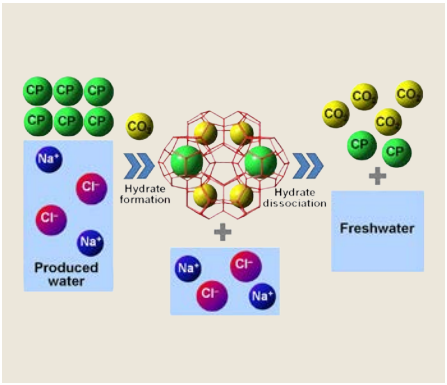
Power plants account for the largest share of freshwater withdrawals in the United States.



This map, created through BLOSOM, shows a hypothetical deepwater well blowout after 40 days.



Enhanced Fayetteville Shale Information System showing watershed layers and information by area.



This diagram shows how gas hydrate-based desalination works. Selected hydrocarbons help hydrate formation to occur even with high-salinity "produced" water. Potable freshwater can later be separated from the hydrate.

New 3-D Monitoring Tool Predicts Outcomes of Deepwater Blowouts—NETL, in partnership with the Oak Ridge Institute for Science and Education, has developed a new 3-D modeling tool designed to simulate the outcomes of deepwater and ultra-deepwater oil well blowouts. The Blowout and Spill Occurrence Model, or BLOSOM, is an integrated suite of modeling tools that allows users to predict these blowouts, which are often more complicated than traditional oil spills.

BLOSOM includes a traditional spill transport and oil weathering component, plus components that can track the plume coming from a blowout at the seafloor and model the properties of crude oil, gases, and hydrates. These components take into account the multiple environmental uncertainties associated with deepwater and ultra-deepwater blowouts. They can run individually or work together as a single system, giving BLOSOM a flexibility that makes it ideal for modeling risk-assessment and response scenarios for which existing data may be sparse or nonexistent.

BLOSOM is currently in beta testing and has been included in an American Petroleum Institute modeling intercomparison study.

NETL Assessment Tool Informs Decisions About Arkansas Water Use—The Arkansas Natural Resources Commission (ANRC) is modeling the availability of surface and underground water resources in watersheds of the Fayetteville shale area using a soil and water assessment tool, or SWAT, developed cooperatively by NETL and the University of Arkansas's Center for Advanced Spatial Technology.

The new SWAT, which combines a state-of-the-art water resource simulation model with a geographic information system, can help the ANRC make science-based decisions about water withdrawal volumes, durations, and timing during the water withdrawal permitting process. Modeled results can also help the ANRC set appropriate allocation levels during times of water shortage.

A SWAT is a critical tool used by the gas industry and regulatory agencies to manage water resources. Decision-support systems that include SWATs provide a transparent accounting of water supplies, including regularly updated estimates of surface water availability. Such systems also help reduce potentially adverse impacts of hydraulic fracturing by predicting how withdrawing water from ground and surface sources will affect water quality and availability.

Innovative Desalination Process Removes 90 Percent of Salt from Wastewater—Scientists at NETL are developing an affordable method to turn briny wastewater produced during hydraulic fracturing and other oil and gas extraction processes into potable water for drinking and irrigation. Oil and gas extraction produces roughly 10 barrels of briny water for each barrel of oil. In dry regions, this water could become a valuable resource, but traditional desalination methods, such as thermal distillation and reverse osmosis, have historically been energy intensive and cost prohibitive.

Gas hydrates contain only pure water and gas, so when hydrates are formed, salt and other impurities are excluded. This makes gas hydrates ideal for desalinating wastewater for potable use. Traditional methods for gas hydrate desalination are economically unfeasible, however, because the water must first be chilled below 32 °F in high-salt conditions for gas hydrates to form.

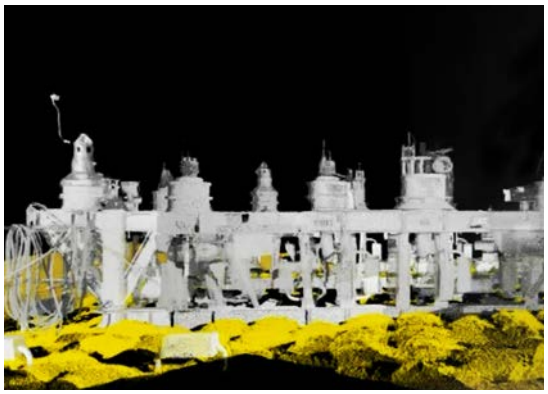
NETL researchers have discovered that combining CO_2 gas with select hydrocarbons forms gas hydrates from wastewater at near-room temperatures. This method increases the energy efficiency of the desalination process and removes 90 percent of the salt from wastewater, making it an affordable desalination method.

This test facility for dry cooling technology simulated the operating conditions of a full-scale power plant cooling system, allowing researchers to estimate the performance of a full-scale desiccant dry cooling system and monitor for potential environmental impacts.

Dry Cooling Technology for Power Plants Eliminates Use of Cooling Water—Thermoelectric power plants typically use either wet (with water) or dry (without water) cooling systems to condense the steam that drives a turbine. Wet cooling is more cost-effective than dry cooling, but it requires large amounts of water—nearly 90 percent, in fact, of the water used by a power plant equipped with this type of system. Through the NETL Power Plant Water Program, the University of North Dakota's Energy & Environmental Research Center (EERC) has developed a dry cooling system that could nearly eliminate water use in thermoelectric power plants without the usual cost and performance penalties.

EERC's non-evaporating liquid desiccant cools steam by directly transferring heat from the desiccant to the atmosphere. It offers many advantages over conventional wet and dry cooling: it eliminates water withdrawal for the cooling process, it can be continuously recirculated, it imposes a smaller loss in overall system performance than conventional dry cooling, and it eliminates the impact on local waterways made by discharging salty blowdown water from the cooling tower.

Based on these pilot results, EERC conducted a system study for 300-megawatt-electric coal power plants in Gillette, WY; Atlanta, GA; and Phoenix, AZ, that indicated its technology maintains 40 percent lower annual cooling system costs when compared to a traditional air-cooled condenser.



Marlin's new high-resolution scanning allows unprecedented as-built drawing accuracy.

Marlin Receives a 3-D Upgrade—Lockheed Martin has successfully developed an autonomous underwater vehicle (AUV) inspection system for use in deepwater oil fields. The Marlin™ AUV can perform subsea structural inspection tasks up to four times more efficiently than human divers or remotely operated vehicles, thereby reducing the surface operational footprint by 75 percent and eliminating the need for large surface-support vessels.

With sonic imaging, the Marlin was already capable of detecting large discrepancies, such as bent, broken, or missing members of a subsea structure. Now, a new 3-D laser imaging capability added in 2013 allows Marlin to produce high-resolution images at millimeter scale to evaluate minute details, like the degree of corrosion on a surface, and it can produce engineering drawings as well.

The Marlin's ability to autonomously detect anomalies within an underwater facility in real time can help reduce the risks and enhance the environmental performance of ultra-deepwater drilling. Implementing inspection, repair, and maintenance operations using AUVs in ultra-deepwater fields will provide game-changing improvements in safety, performance, reliability, and cost and enable production of smaller deepwater fields, as well.

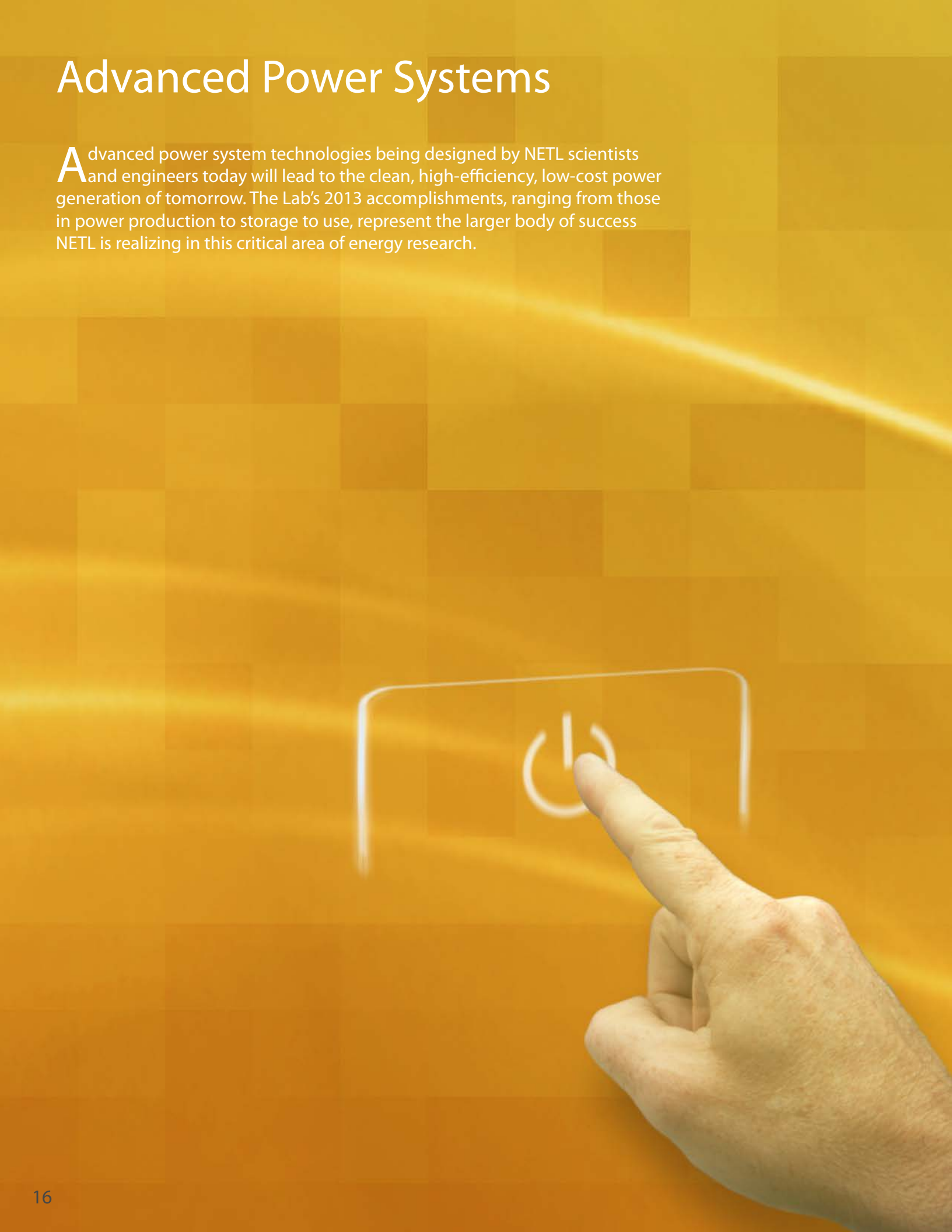
This research was undertaken as part of the Research Partnership to Secure Energy for America program managed by NETL.

What is RPSEA?

Under contract with NETL, the Research Partnership to Secure Energy for America (RPSEA) has managed a 7-year ultra-deepwater program to develop new technologies necessary to reduce the safety and environmental risks of producing offshore energy resources. The overarching RPSEA program—which also includes research associated with production of unconventional natural gas and oil—was established to help meet the nation's growing need for hydrocarbon resources produced from reservoirs in America. The RPSEA program is scheduled to end in 2014.

Advanced Power Systems

Advanced power system technologies being designed by NETL scientists and engineers today will lead to the clean, high-efficiency, low-cost power generation of tomorrow. The Lab's 2013 accomplishments, ranging from those in power production to storage to use, represent the larger body of success NETL is realizing in this critical area of energy research.



Flywheel energy storage at this Beacon plant works as a mechanical battery. A rotor spins at an incredibly high speed, storing rotational energy, which is converted back by slowing down the flywheel to provide instantly available energy as needed.

The stainless steel photocatalysis cell and gold-zinc oxide nanoparticles pictured here can convert sunlight into thermal energy and catalyze the transformation of CO_2 into usable light gases.

Flywheel Energy Storage Plant Begins Operation—Hazle Spindle, LLC, in conjunction with Beacon Power, began commercial operation of a flywheel energy storage facility in Hazle Township, PA. The flywheels are mechanical devices designed to temporarily store surplus energy that may otherwise be lost and quickly inject it back into the power grid when there is an energy demand. Flywheels are built to last 20 years or more with virtually no maintenance required in the mechanical portion of the system.

Fast-response energy storage resources, like flywheels, can correct energy imbalances more rapidly (on the order of milliseconds) and more efficiently than traditional generators, and they do this without consuming additional fuel, producing emissions, or using hazardous materials or water.

The Hazle storage facility began providing 4 megawatts of energy storage capacity for frequency regulation services in the Pennsylvania-Jersey-Maryland interconnection market in September 2013. The plant is expected to reach full storage capacity at 20 megawatts in 2014. As a result, electricity users should benefit from lower costs and a more stable, resilient power grid.

The project is one of 32 projects funded by the American Recovery and Reinvestment Act of 2009 through a cooperative agreement under DOE's Smart Grid Demonstration Program. It is managed by NETL for the Office of Electricity Delivery and Energy Reliability.

Nanometer-Sized Heaters Developed for CO_2 Management and Conversion—NETL and West Virginia University researchers have developed a new material that converts visible sunlight into thermal energy. That energy then catalyzes the transformation of CO_2 into methane, carbon monoxide, and other useable light gases. The new development relies on a unique heating mechanism that uses light to excite electrons in nanometer-sized metal particles. The excited electrons then collide with the crystal lattice of the nanoparticles, generating heat.

The team has developed several catalyst systems that rely on nano-sized particles—the only size particles that can absorb visible light—of gold and other materials as the heater and zinc oxide as the catalytically active substrate. Experiments show that low-intensity visible light can heat the gold-zinc oxide catalysts to approximately 600 °C, with the light intensity dictating the light-gas end product.

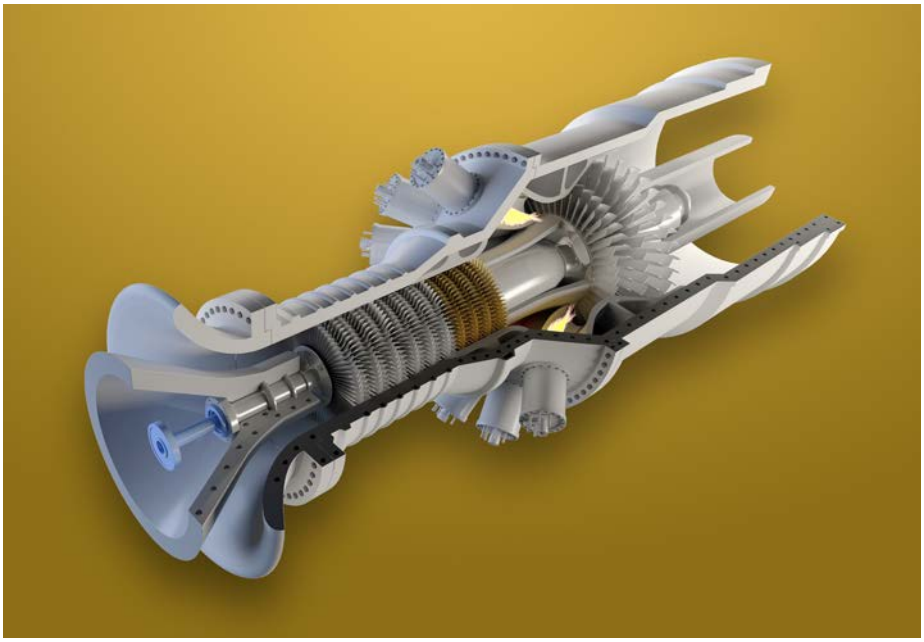
These results are further described in the international journal *Nanoscale,* published by the Royal Society of Chemistry (*Nanoscale*, 5, 6968, [2013]). A U.S. provisional patent has been filed on this technology.

Did you know?

Pyrochem Catalyst Corporation licensed a new NETL patent issued in 2013, a method to design and utilize a mixed metal oxide-based catalyst system for fuel processing with minimal catalyst deactivation. The catalyst can be used in a number of applications, such as syngas production for chemical, fuel, and power production and in catalytic combustion and cleanup technology. This is the second NETL patent licensed by Pyrochem Catalyst, a Pittsburgh-based start-up company, as they pursue commercial development of NETL's pyrochlore catalyst technology.

feature article

NETL's Hydrogen Turbine Program Delivers Improved Turbine Performance



Advanced turbines, with parts that can withstand the high temperatures of advanced power plants, can produce power more efficiently and economically.

Gas turbines are responsible for the vast majority of power production in the United States and the world. Advancing hydrogen turbine performance in an integrated gasification combined cycle (IGCC) power plant offers the most significant near-term performance benefit for reducing emissions and cost while increasing efficiency in a coal-fired plant.

Because the Energy Department is committed to using coal in cleaner, more efficient ways that reduce CO_2 and other emissions, NETL is pursuing hydrogen turbines in an IGCC application as one of the cleanest and lowest-cost ways to capture CO_2 in a coal-based power plant.

One key to a turbine's fuel-to-power efficiency is the temperature at which it operates. Higher temperatures generally mean higher efficiencies, which in turn can lead to more economical operation. But the first-stage temperatures in a power plant can be in excess of 2,600 ˚F, potentially exceeding current metal airfoil melting points. To counter this, advanced cooling concepts and thermal barrier coatings are key technologies that can limit the thermal exposure of these turbine components to elevated temperatures.

Recognizing the need to develop the next generation of gas turbines, DOE sponsors a program to advance gas turbine technology for coal-based power generation to improve efficiency, reduce emissions, lower costs, and allow for carbon capture and storage.

Managed by NETL, the Hydrogen Turbine Program is focused on developing advanced components and technologies for turbines that provide tangible benefits to the public. The program's emphasis is on understanding the underlying factors affecting combustion, aerodynamics, heat transfer, and materials for gas turbines. Specific areas of research include improving computational modeling, combustor technologies, materials research, enhanced cooling technology, and coatings development.

One of the major achievements of the turbine program was overcoming previous limitations on turbine temperatures by using a combination of innovative cooling technologies and advanced materials. The turbine components developed within this research program have also optimized methods to boost turbine inlet temperatures, resulting in higher operating efficiencies while limiting critical criteria pollutants, specifically nitrogen oxides.

One area of our research that has helped make this accomplishment possible is an innovative airfoil manufacturing technology that promises to improve the performance and longevity of gas turbines. Poised for commercial deployment, Mikro Systems, Inc.'s, patented Tomo-Lithographic Molding (TOMO®) manufacturing process was harnessed through NETL for use in gas turbine airfoils. The new airfoil design, using the TOMO technology, is now being produced in Siemens Energy's new turbine component manufacturing facility that opened in Charlottesville, VA, in 2013.

TOMO, which is expected to contribute to cleaner, more reliable, and affordable domestic energy production—as well as create new high-tech manufacturing jobs—was licensed by Siemens Energy

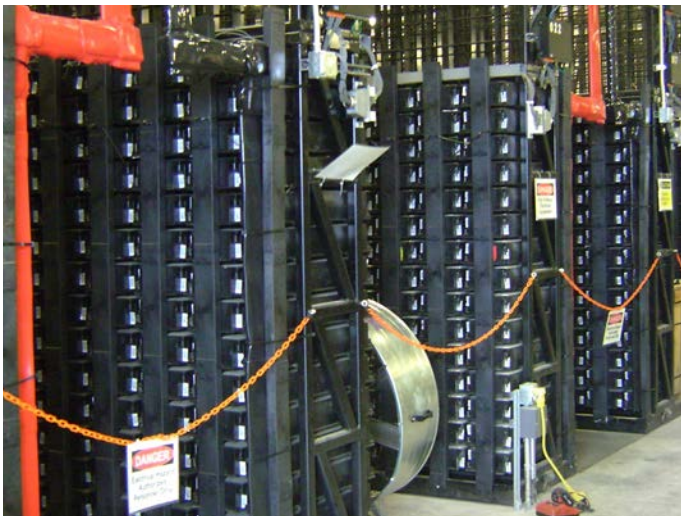
in 2011. TOMO enables rapid, cost-effective development and production of high-performance products made from metals, ceramics, polymers, and composite material systems. Applied to gas turbines, it enables more sophisticated airfoil designs with improved cooling characteristics that lead to higher operating temperatures and improved efficiency.

The TOMO technology enables rapid, cost-effective manufacturing of ceramic cores used to case advanced turbine blades and provides features not possible by conventional fabrication methods. (Image courtesy of Mikro Systems)

Mikro Systems received Energy Department support through the American Recovery and Reinvestment Act and multiple Small Business Innovation Research grants to apply its TOMO technology to gas turbine airfoils. This project directly addresses the need for rapid, cost-effective manufacturing of advanced turbine blades that will improve the performance and reduce the cost of electricity produced by IGCC power plants.

Through our own onsite research, collaborations with U.S. universities, national laboratories, and partnerships with turbine manufacturers, NETL is making great strides in advancing more efficient and lower-cost power plants with CO_2 capture. These advanced power plants are made possible—and our economic and energy security are enhanced—by retaining U.S. technology leadership in high-performance gas turbines.

LED drivers are current control devices that replace the need for resistors. The drivers respond to the changing input voltage while maintaining a constant amount of current to the LED.



This battery bank at Notrees stores wind energy and returns it to the power grid as needed. (Image courtesy of Duke Energy Business Services, LLC)

Philips Lighting Electronics Introduces a New Family of Drivers—A project managed by NETL on behalf of the Office of Energy Efficiency and Renewable Energy could help drastically reduce the amount of electricity the United States uses for lighting.

Philips Lighting Electronics of North America introduced a family of new power supplies, commonly called drivers, for a wide variety of LED lighting applications. These drivers are smaller and more efficient than the previous generation of similar products and are designed for outdoor applications. The drivers were developed by the company's LED system team in Rosemont, IL, and made possible with DOE's investment in key enabling technologies, such as resonant switching.

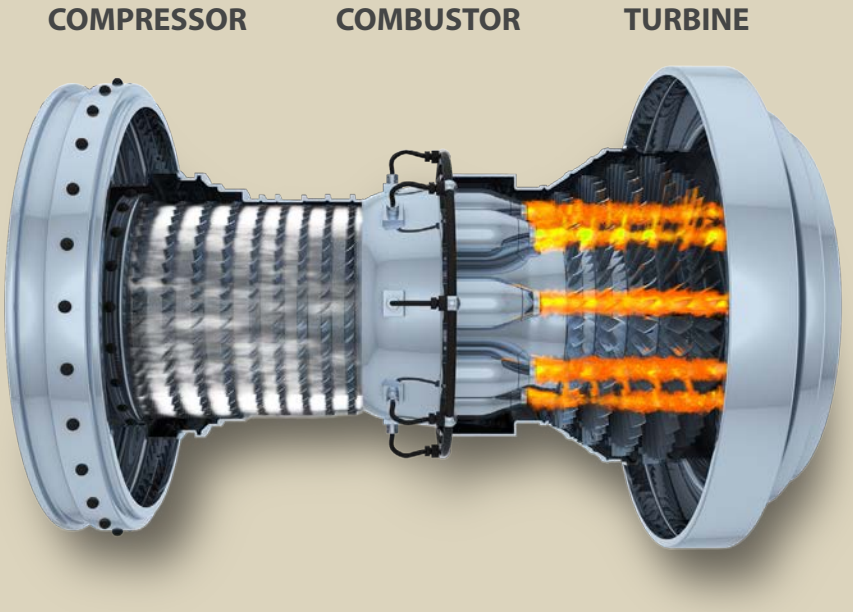
Driver efficiency, along with thermal and light extraction efficiencies, are key elements in making highly advanced solid-state lighting luminaires. By 2030, solid-state lighting could reduce national electricity use for lighting by nearly one half—representing the output of 50 1,000-megawatt power plants and an annual savings of $30 billion.

Award-Winning Notrees Battery Project—An NETL-managed project is helping redefine the future of energy storage. A battery storage facility integrated with Duke Energy's 153-megawatt Notrees Wind Farm near Odessa, TX, has been successfully providing fast-frequency response service to the grid since February 2013. It is a first-of-its-kind facility to operate under this highly regulated and controlled operational protocol.

The Notrees storage system regulates the wind farm's naturally variable output by using batteries to store energy generated by wind turbines, returning that energy back to the grid in brief bursts that are critical to maintaining grid integrity. The $44 million system, America's largest battery-storage project, was constructed under the Smart Grid Demonstration Program with $22 million in matching funds from DOE.

In 2013, the Notrees Storage Facility was recognized with a Top Utility-Scale Energy Innovation Award, presented at the Energy Storage North America Conference and Expo in San Jose, CA. Award winners were judged on services provided to the grid, financing options, ownership models, and technology strengths. NETL's Office of Energy Project Management manages this and other smart grid demonstration projects in support of DOE's Office of Electricity Delivery and Energy Reliability.

How gas turbines work



In gas turbines, incoming air is compressed to high pressure in the compressor section, and then heated to high temperature by the combustion of fuel in the combustor section. The high-temperature, high-pressure gas then passes through a series of rotor-mounted airfoils, causing them to rapidly spin, thereby converting the kinetic energy of the moving gas into mechanical work.

What is an IGCC power plant?

An integrated gasification combined cycle power plant uses a gasifier to turn coal and other carbon-based fuels into synthesis gas (syngas). The IGCC process then removes impurities from the syngas, after which the syngas is converted to separate streams of hydrogen and CO_2. The CO_2 is pure enough to be compressed and stored while the hydrogen-rich syngas fuels a combustion turbine.

Excess heat from the combustion turbine is passed to a steam turbine, and the combustion and steam turbines work together to generate power. The process results in improved efficiency compared to a conventional pulverized coal-based power plant and offers options for a significant reduction in CO_2 emissions.

Reliable Supply

A consistent, reliable supply of energy is essential for the economic health and energy security of the United States. NETL is committed to discovering and improving techniques and technologies to produce, protect, and improve the energy chain for our nation today and in the future.

These gray cylindrical modules contain membranes that separate sodium sulfide into its component elements, sulfur and sodium. The sodium is then reused as a reactant in Ceramatec's petroleum upgrading process.

Operators of this 1953 power plant have replaced its coal- and oil-fired boilers with boilers that burn forest residue and discarded tires.

Innovative Technology Improves Upgrading Process for Unconventional Oil Resources—Ceramatec, Inc., (Salt Lake City, UT) has developed an innovative technology for upgrading unconventional petroleum resources, including heavy oil, shale oil, and tar sands bitumen, as part of a DOE-funded project managed by NETL. The technology combines an alkali metal, like sodium, with hydrogen or methane to remove sulfur, nitrogen, and metal contaminants from crude oils. It then regenerates the alkali metal for reuse to improve process efficiency.

The new approach creates a smaller carbon footprint than traditional processes because it can use methane directly instead of requiring hydrogen as a feed gas. It also has the potential to improve economics across industry by increasing product yields, directly improving the quality of the end products, and reducing the need for expensive processing equipment at refineries. Finally, because this technology contributes to developing domestic energy resources, it can help reduce our nation's dependence on foreign oil supplies.

Ceramatec's technology operated successfully under test conditions for more than 10,000 continuous hours. A pilot-scale reactor is now planned for installation at a site near Ft. Saskatchewan in Alberta, Canada.

Award-Winning Energy-Savings Project Celebrates First Year of Operation—The Biomass Cogeneration Power Plant at the Savannah River site in Aiken, SC, completed its first year of successful operation on March 3, 2013. In its first year, the plant used 10,000 tons of local landfill tires and 221,000 tons of forest waste to produce 1.67 billion pounds of steam and 97,000 megawatts of electricity. The plant's two massive tire- and wood-burning boilers replaced four Cold-War-era coal- and oil-fired boilers as part of the largest energy savings performance contract completed by the Federal Energy Management Program.

NETL helped negotiate the 20-year contract and provided technical expertise on sustainable biomass harvesting and the technologies used to convert biomass into steam and electricity. Approximately 800 jobs were created during the facility's design and construction, and more than 200 long-term jobs support ongoing operations.

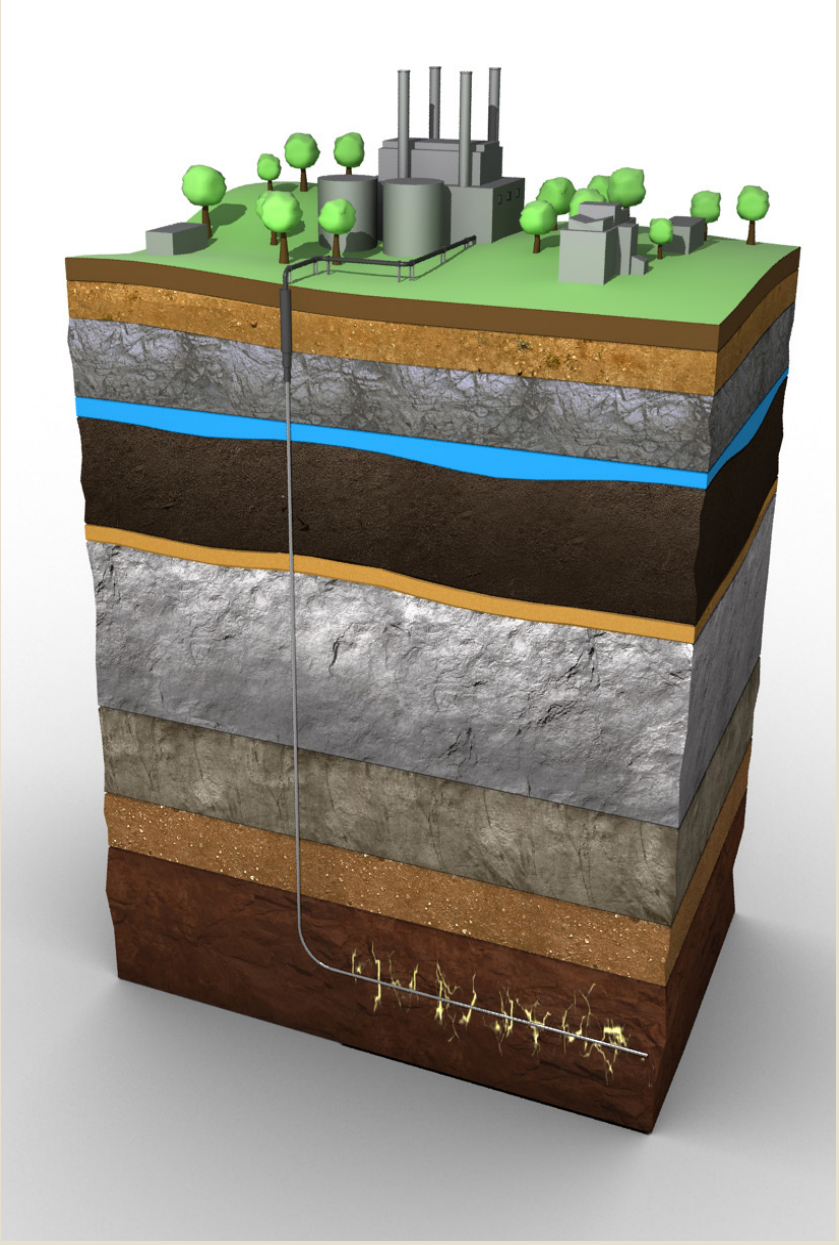
Installed by Ameresco Federal Solutions, Inc., the Savannah River Site Biomass Cogeneration Facility has received numerous awards, including the 2012 DOE Office of Environmental Management Best-in-Class Sustainability Award, the 2012 Renewable Energy World Bioenergy Project-of-the-Year, and the 2012 "Groundbreaker of the Year" at the International Biomass Conference & Expo.

Did you know?

FracFocus 2.0, a voluntary registry for the disclosure of chemicals used in fracking, was launched by NETL in 2013. It contains data on more than 40,000 wells and was used by 10 states in 2013 as a means of official chemical disclosure.

feature article

The Shale Gas Boom: What's Going On?



Horizontal drilling with hydraulic fracturing (fracking) of the shale layers to release natural gas for extraction.

Shale gas—natural gas trapped in layers of shale rock—is considered an unconventional gas resource. Shale is not permeable enough to allow trapped natural gas to flow to a well bore. The gas is "locked" in the rock, and the shale reservoir must be stimulated to enable the gas to flow into a well and on to the surface.

History: For many decades, although producers knew that natural gas lay in the shale, low flow rates prevented them from drilling for it. Then, in the 1960s and 1970s, conventional natural gas reservoirs became more difficult to find, and the nation's natural gas supply was at risk. In 1977, the U.S. Congress authorized and funded an Unconventional Gas Research Program to investigate and quantify shale gas, gas sands, and coal-bed methane. The predecessor to DOE, the U.S. Energy Research and Development Administration, implemented the program through the Morgantown Energy Research Center, which later became part of NETL under DOE.

Early DOE-industry demonstrations accelerated the development of technologies such as horizontal drilling, large-volume hydraulic fracturing, micro-seismic fracture mapping, and electromagnetic telemetry. These research and development efforts helped to jump-start some of the technologies that enable today's commercial production of natural gas from shale.

Horizontal Drilling: One problem with developing shale gas resources was that a normal vertical well could only intersect a small volume of the shale reservoir. Only the natural gas in close proximity to the well could be accessed. Research revealed that the way to profitably produce shale gas was to develop a means to economically drill a well horizontally to follow the rock layers. NETL drilled the first high-angle Devonian shale well in 1975. In 1986, NETL drilled a horizontal wellbore 2,000 feet into the shale layer. This well initially produced 10 times the average amount of gas recovered from vertical wells in the area, demonstrating that horizontal drilling could be one part of the answer to the shale productivity puzzle.

Hydraulic Fracturing: Hydraulic fracturing of the shale layers to release natural gas is accomplished by creating high-fluid pressure in the wellbore next to the producing formation. Water, sand, and chemicals are pumped down a well after it has been drilled to create fractures in the formation that can act as flow paths for the natural gas. The fracturing flowback water recovered with the natural gas can be cleaned and reused in fracturing other wells. The sand accompanying the water is left behind to prop open the new fractures so natural gas can escape into the well after the fluid pressure has been relieved.

DOE Contributions: Over the years, collaborative efforts between DOE and industry continued to add to shale gas recovery research. In addition to the first air-drilled horizontal Devonian shale well mentioned above, researchers recovered the first core from a horizontal air-drilled shale well; were first in successfully using external-casing packers in a horizontal well; and completed the first horizontal well with seven individual hydraulically fractured intervals.

In 1977, NETL, with Columbia Gas, introduced large-scale massive hydraulic fracturing for shale gas recovery in the eastern United States at a Lincoln County, WV, test site. Here, NETL also introduced electromagnetic measurement-while-drilling to steer downhole motors in air-drilled holes. NETL conducted more than 13 field tests, which ultimately led to successful commercial application of the technology in the United States and western Canada.

Into the future: In 2013, under DOE's Office of Fossil Energy, NETL began seeking partners interested in conducting field research that would provide an unbiased perspective on the environmental impacts of shale-gas production. Because horizontal drilling and multi-stage hydraulic fracturing are raising public concern, NETL wants to document environmental conditions before shale gas development (to establish a baseline) and during its production. NETL is also developing science and technology strategies that will reduce the risk of adverse environmental events and ensure that, if they do occur, they can be detected quickly and mitigated.

Dynamic line rating technology monitors real-time line capacity to help relieve costly congestion caused by transmission constraints and contingencies.

USGS technicians deploy instruments at the start of a seismic survey to explore gas hydrates in the deepwater Gulf of Mexico from April to May 2013. (Image courtesy of the U.S. Geological Survey/photo by Patrick Hart)

Utility Completes Smart Grid Demonstration Project—Oncor Electric Delivery Company and its partners demonstrated a comprehensive dynamic line rating system that is now helping parts of Texas more effectively manage power transmission.

Integrated dynamic line rating, or iDLR, brings together a variety of instruments and sensors currently available in the marketplace to report, in real time, the impact of temperature changes, solar radiation, and wind variations on power line tension. System operators and transmission owners can use this information to accurately determine line capacity. In doing so, they can increase capacity limits by 6–14 percent above ambient adjusted rating under certain ambient conditions (84–91 percent of the time). The iDLR can allow an increase in power capacity ratings through existing transmission lines with minimal additional capital investment, enhance the ability to dispatch wind power, and mitigate congestion on heavily loaded circuits. The demonstration was so successful that Oncor has deployed iDLR on five additional transmission lines near Odessa, TX.

This project, the largest DOE-supported dynamic line rating project to date, is one of 32 projects using funds provided by the American Recovery and Reinvestment Act of 2009 under DOE's Smart Grid Demonstration Program. It is managed by NETL for the Office of Electricity Delivery and Energy Reliability. The final report has been published through DOE's Office of Scientific and Technical Information and the Smart Grid.gov website.

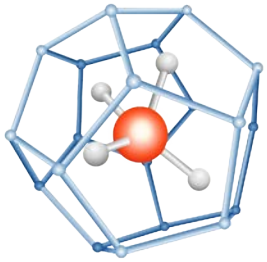
Collaborations Enhance Methane Hydrate Knowledge—NETL is developing the tools and technologies to enable environmentally safe methane hydrate production from domestic Arctic and offshore deposits. The challenges involved in developing this potentially rich source of natural gas are best solved through international collaboration due to the presence of deposits around the globe. In 2013, NETL researchers cooperated on several international methane hydrate projects.

Japan: Researchers from the U.S. Geological Survey (USGS) and Georgia Institute of Technology, along with Japanese scientists, are using cutting-edge technology to study rare gas hydrate samples recovered from deep beneath the seafloor. This research, part of an ongoing Japanese collaboration on methane hydrate research with DOE and the Gulf of Mexico Gas Hydrate Joint Industry Project, advances understanding of the global distribution of gas hydrates and how the methane might be used as a viable energy source.

Gulf of Mexico: NETL joined USGS and the Bureau of Ocean Energy Management for a 15-day methane hydrate research expedition in the northern Gulf of Mexico. The mission resulted in high-resolution seismic data and imagery that researchers will use to refine estimates of the nature, distribution, and concentration of the methane hydrate resources in that area. This research took place in the same area where, in 2009, a DOE-funded drilling expedition first discovered the methane hydrate reservoirs.

Alaska: NETL released data from an innovative test to release natural gas from methane hydrate at the Iḡnik Sikumi test well on the Alaska North Slope. The production trials were conducted in 2012 by NETL, ConocoPhillips, and the Japan Oil, Gas, and Metals National Corporation. The goal was to determine if a CO_2 exchange technology developed by ConocoPhillips and the University of Bergen, Norway, could enhance methane hydrate extraction while storing CO_2.

In a separate effort, the Alaska Department of Natural Resources and DOE signed a memorandum of understanding to improve cooperation and collaboration between the two agencies through energy research and development. The agreement promises to advance our nation's understanding of methane hydrate. It will be implemented by the Office of Fossil Energy and NETL.



Methane Hydrates

Methane hydrate is formed when methane molecules—the chief component of natural gas—become trapped within a cage-like lattice of ice at low temperature and high pressure, primarily under Arctic permafrost or beneath the ocean floor.

Researchers study methane hydrate as a possible energy source and out of concern that climate change could cause an increase in the release of methane, itself a potent greenhouse gas, into the ocean or atmosphere.

Did you know?

Dynamic line rating (DLR) is a real-time overhead electric transmission line monitoring methodology that uses various sensing technologies to determine the maximum power-carrying capacity of the lines while respecting system design limits.

DLR provides more accurate and generally higher ratings than the static ratings that the industry typically uses, because DLR is based on actual conditions at a specific moment rather than on a set of assumed, near "worst-case scenario" conditions. Thus, DLR allows system operators to maximize capacity to relieve congestion on heavily loaded transmission lines.

Science & Technology Leadership

NETL scientists and engineers have proven once again to be leaders in their fields. In 2013, they shared knowledge, tools, and innovations with other organizations inside and outside the energy arena. They also received more than a dozen patents for their technologies, bringing those discoveries one step closer to commercial viability.

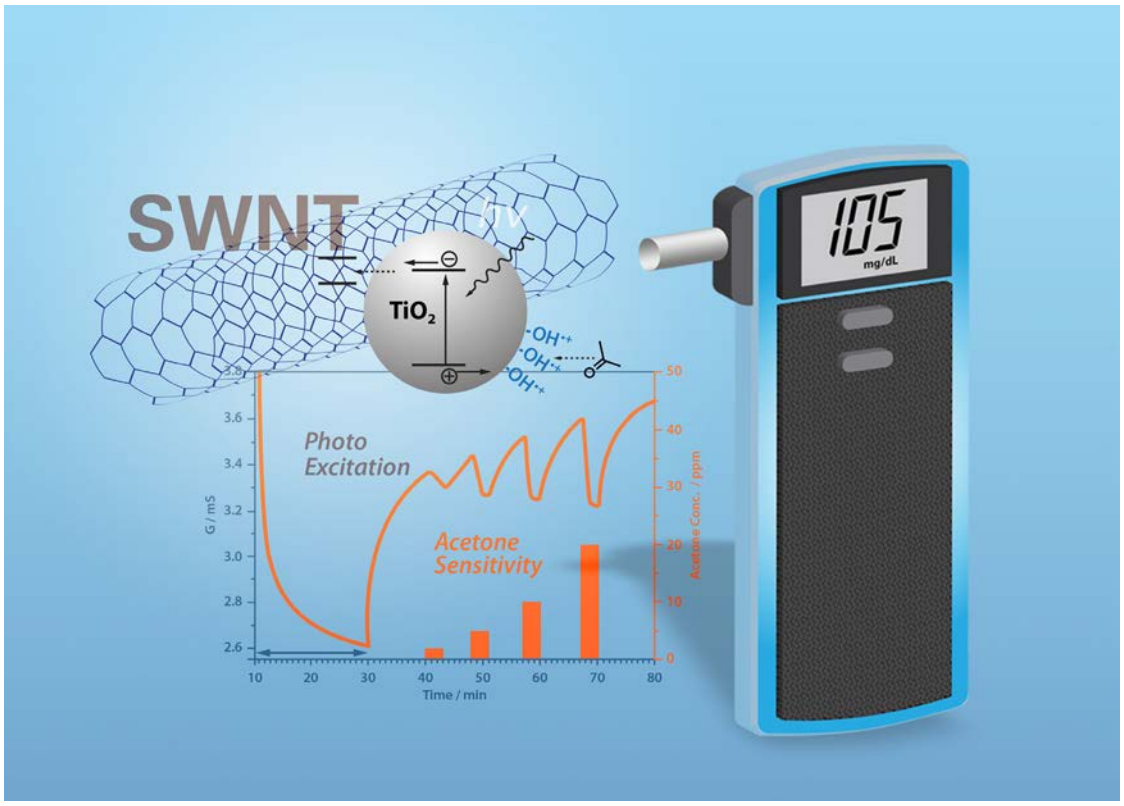


Illustration of an acetone molecule adsorbed on a titanium dioxide cluster at the surface of a carbon nanotube. A hypothetical diabetes breathalyzer device is shown on the right.

New Material Shows Promise for Diabetes Testing—NETL's Office of Research and Development and affiliated university colleagues have developed a new hybrid nanostructure material that may be used in an inexpensive breathalyzer to monitor blood glucose.

The research team discovered that, by bolstering carbon nanotubes with titanium dioxide, they could produce an electrical semiconductor with ultra-high sensitivity to acetone vapors. When glucose levels rise in persons with diabetes, their breath produces a higher concentration of acetone as compared to persons without diabetes. Since the hybrid nanostructure displays unique behavior when exposed to ultra-violet illumination, it can help differentiate an elevated amount from a normal amount.

Carbon-nanotube-based sensors are extremely small and inexpensive, consume little to no power, and are compatible with complementary metal-oxide-semiconductor technology, making them ideal for chemical sensing and non-invasive medical diagnostic tools.

When used as a sensing tool in a breath analyzer, the new material could offer millions of people with diabetes a non-invasive alternative testing method for blood sugar. The NETL team is now developing a prototype sensor, which, if it operates successfully in clinical trials, could prove to be a game-changing medical technology for glucose monitoring.

Did you know?

Because sensors based on carbon nanotubes are compatible with complementary metal-oxide-semiconductor technology, they could potentially be incorporated into modern electronic devices, including smart phones.

feature article

The NETL Energy Data eXchange Helps Researchers Work Together by Sharing Results

Sharing energy knowledge and expertise to encourage collaboration among a wide range of energy experts became easier in 2013 with the launch of NETL's Energy Data eXchange, or EDX, a comprehensive network of fossil energy-related datasets and tools that allow scientists to put research results to work across a spectrum of energy topics.

EDX houses primary R&D data. EDX makes data generated by NETL -affiliated researchers and other EDX users available almost instantly through a common portal designed to encourage and support efficient and timely science-based inquiry and analysis. EDX is constantly growing and evolving with user input, new content, connectivity, and tools to make coordination and collaboration efficient for EDX users and stakeholders.

EDX facilitates connections. In EDX, collaborative workspaces help NETL-affiliated researchers nurture ongoing research quickly and cost-effectively in a secure, private environment from across the office or across the world. In addition, EDX's multi-organizational

search capabilities allow users to search externally hosted information and link to key publically available energy-related data. Public features, such as EDX tools, EDX groups, and EDX portfolios, promote more efficient information sharing, technology development, and knowledge and technology transfer.

EDX is secure. The system provides three tiers of access, ensuring that information is only shared when it's meant to be. *Open-access* data is available to the public for download and represents the knowledge transfer half of EDX. *Restricted data* is available to registered users as appropriate. *Collaborative working data* is proprietary and securely shared among designated members of identified teams. To further promote a secure environment, open-access and restricted data is checked for quality before being made available. The data is then subject to continuous monitoring by all users.

EDX adapts to user needs. As an evolving platform, EDX is being developed in response to the needs of its users. This user-driven approach will keep EDX relevant, improve its content and capabilities, and ensure that it is a continuously growing and evolving tool that meets the needs of the energy research community.

Because NETL administers wide-ranging fossil energy research projects and maintains a highly specialized talent base, knowledge management and efficient information transfer are strategic priorities. EDX is dynamically aligning and sharing relevant data to fill immediate needs across our organization. NETL understands that the ability to keep researchers connected allows them to create productive relationships and solve today's energy challenges efficiently. EDX meets the growing demand to access, share, and publish data and data-driven products in support of science-based decision making. Researchers can visit EDX at www.edx.netl.doe.gov to explore, join the system, and participate in its evolution.

What's in the EDX toolbox?
EDX houses a suite of data-driven applications created by NETL researchers to facilitate the use of data and information related to and resulting from NETL projects. These tools leverage the results of NETL research and help transfer energy knowledge to researchers, policy-makers, regulators, and the general public. Combined, they extend EDX's capabilities, ultimately improving access to key information, furthering research efforts, and fostering efficient collaboration.

Geocube is a web application that allows users to produce custom maps that integrate standard geographic elements with non-geographic elements like oil and gas wells, power stations, and recreational and commercial facilities. The pre-populated data within Geocube is currently focused on the Gulf of Mexico to support research at NETL related to offshore oil and natural gas spill prevention. However, NETL is continuing to add datasets from other regions as well: next up is the Appalachian Basin. Users can also upload information from any location worldwide to take advantage of Geocube's web-mapping capabilities in support of their specific research.

geoWELL is a map-based application that links users to online sources of subsurface geologic information and information about oil and gas wells, CO_2 injection, and other underground injection and production sites. Links to federal, state, and tribal agencies help users quickly find primary sources of information related to selected geographical areas. The application also helps NETL researchers and analysts find information important to studying the resources, risks, and impacts associated with fossil energy production.

MFiX (Multiphase Flow with Interphase Exchanges) is an NETL-developed open-source computer code capable of describing systems in which solids and liquids interact under complex conditions. Existing previously as a standalone system, MFiX joined EDX tools in 2013. MFiX reduces the time and cost of advanced energy technology development by evaluating innovations in systems design using science-based simulations. Through EDX, users can download the MFiX code and documentation and see examples of code application.

With new tools and applications planned for 2014, the EDX toolbox will continue to grow and evolve to meet the needs of its users and support NETL's knowledge transfer goals.

This customized map from Geocube shows the locations of offshore wells in the Gulf of Mexico.

NETL-Developed Technologies Receive U.S. Patents—Research efforts by NETL and its partners were recognized by the issuance of 15 patents in 2013. Deployment of these NETL-developed technologies will result in reduced emissions, more efficient power plants, and lower energy production costs—all of which have a direct impact on U.S. energy consumers.

NETL's 2013 patents are as follows:

- A fabrication method for fiber-supported ionic liquids for chemical separation
- An improved catalyst system for reforming hydrocarbon fuels
- Nanocomposite films for use in high-temperature optical gas-sensing devices
- A process and device for the rapid formation of gas hydrates
- Three patents related to sorbent materials for CO_2 capture
- An advanced turbine airfoil configuration for improved surface cooling
- A sensory access probe for process monitoring in harsh environments
- A method to measure particle motion in circulating fluidized-bed reactors
- The development of a flow modulation valve for gas turbine operations
- A thermal method to deactivate high-carbon fly ash
- Reduced palladium-containing membranes for improved hydrogen separation
- A pulse-jet mixer for the suspension of heavy solids within a carrier fluid
- A process to improve the water-gas shift reaction for hydrogen production

Patenting technologies protects U.S. taxpayer investments in energy-related research. NETL fosters the continued development of new technologies, with the ultimate goal of transferring them to the marketplace. Many innovations developed at NETL have been successfully transferred to industrial partners, resulting in improved energy efficiency and reduced environmental impact from fossil fuels.

A UUV is deployed during a U.S. Office of Naval Research demonstration near Panama City, FL. (Image courtesy of the U.S. Navy)

NETL Fuel Cell Technology Adapted by the Navy for Unmanned Undersea Vehicles—The U.S. Office of Naval Research is adapting NETL solid oxide fuel cell (SOFC) technology for use in advanced unmanned undersea vehicles (UUVs).

A significant challenge in UUV development is finding a propulsion power source that conforms to strict size limits and meets endurance requirements ranging from days to weeks. Additional considerations include reliability; air-independent operation; refuelability; rapid start-up, shut-down, and load following; and the ability to operate with minimal "observables," like noise or hull discharges.

The Navy believes that an SOFC-based solution could become a transformative technology in meeting ever-broadening mission profiles, enhancing national security, and maintaining maritime superiority into the future. Successfully incorporating NETL SOFCs into UUVs would also provide the electric power industry with valuable SOFC operational experience and contribute to the manufacturing base required for low-cost mass production.

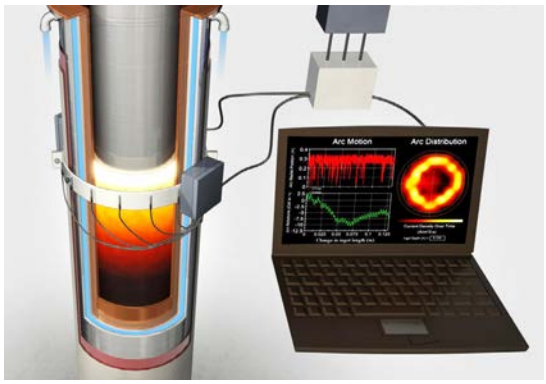
Did you know?

Because SOFCs produce electricity through an electrochemical reaction and not through a combustion process, they are much more efficient and environmentally benign than conventional electric power generation processes. Their inherent characteristics make them uniquely suitable to address the environmental, climate change, and water concerns associated with fossil fuel based electric power generation.

Awards

This section contains a sampling of the awards our scientists and engineers have earned while contributing to NETL's 2013 successes.

Dr. Brian Anderson, a professor of Chemical Engineering at West Virginia University and an NETL research fellow, is a 2013 recipient of the PECASE award, the highest honor the U.S. government bestows on early-career scientists and engineers.



Set-up diagram for the R&D 100 award-winning arc position sensing technology applied to a VAR furnace.

NETL's Coronary Stent Team—Paul Turner, Paul Jablonski, and Ed Argetsinger—was recognized with a 2013 Secretary's Honor Award by the U.S. Secretary of Energy. The team formulated a unique platinum-chromium alloy used to create a new generation of coronary stents for treating patients with coronary artery disease.

Research Affiliate with NETL's Office of Research and Development Receives Presidential Award—NETL-ORD research partner Dr. Brian Anderson of West Virginia University's Department of Chemical Engineering was awarded a 2013 Presidential Early Career Award for Scientists and Engineers (PECASE) for his innovative work in natural gas hydrates and geothermal energy systems.

PECASE awards represent the highest honor the U.S. government bestows on outstanding scientists and engineers in the early stages of their independent research careers. The awards recognize recipients' exceptional potential for leadership at the frontiers of scientific knowledge and their commitment to community service as demonstrated through professional leadership, education, or community outreach. The awards are conferred annually at the White House and are based on recommendations from participating government agencies.

As an NETL-ORD research affiliate and GE Plastics Materials Engineering Professor of Chemical Engineering, Dr. Anderson's research has demonstrated the potential of engineered geothermal systems for substantial commercial and industrial energy production and the promise of methane hydrate as a future natural gas resource. He is recognized at NETL, and in the greater research community, as an up-and-coming leader in these arenas.

R&D 100 Awards Presented for Nanocoating and Monitoring Method—Two technologies advanced by NETL in collaboration with strategic partners were recognized by *R&D Magazine* as being among the 100 most technologically significant products introduced into the commercial marketplace in 2013.

NETL and partner MDS Coating Technologies Corporation (MCT) were recognized for their work in developing an erosion-resistant nanocoating. During aircraft operation, gas turbine engines are continuously exposed to erosive media that damage engine components. Researchers at MCT designed an erosion-resistant nanocoating material and application process that significantly reduces erosion of compressor airfoils. The Federal Aviation Administration-approved nanocoating has the potential to save the U.S. commercial aviation industry up to 100 million gallons of fuel annually and realize cost savings greater than $300 million per year at today's jet fuel prices.

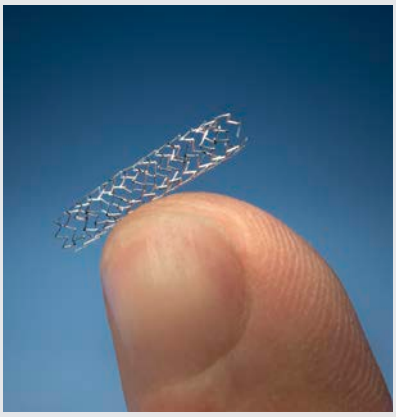
In addition, NETL and partner Allegheny Technologies were recognized for their development of arc position sensing to monitor the melting and refining of specialty metals. Vacuum arc remelting (VAR) is the primary method for processing specialty metals for aerospace and other advanced applications. NETL's arc position sensing technology allows system operators to digitally monitor arc location in real time during melting so they can identify poor operating conditions quickly and avoid known conditions that may lead to defects.

Dr. Malgorzata Ziomek-Moroz holds the award she received from the Corrosion Society for her technical achievements in corrosion engineering.

NETL's Dr. Ziomek-Moroz Wins Award for Corrosion Research—NACE International, the "Corrosion Society," presented NETL's Dr. Malgorzata Ziomek-Moroz with a 2013 Technical Achievement Award. NACE, serving members in 116 countries, awards this honor yearly to recognize technical achievements that have significantly impacted corrosion control or the profession of corrosion engineering. NACE specifically cited Dr. Ziomek-Moroz, an NETL research chemist, for her work in corrosion processes for surface modifications and electrochemical machining of brittle advanced bulk and film metallic materials.

Beyond this award, Dr. Ziomek-Moroz is also recognized in the scientific community for these merits:

- Investigating carbon-induced gaseous corrosion of alloys in solid oxide fuel cells and creating materials for solid oxide fuel cell interconnects
- Contributing to the development of thermal spray zinc and titanium used for bridge protection and investigating corrosion mechanisms of alloys in oil and natural gas environments
- Guiding students into the field of corrosion and corrosion control, where their research has earned recognition through NACE student awards
- Participating in the DOE-sponsored National Science Bowl, which encourages middle and high school students to excel in science, technology, engineering, and mathematics (STEM areas)



Carnegie Mellon
PENNSTATE
University of Pittsburgh
VirginiaTech
WestVirginiaUniversity.
URS

NETL was awarded the Carnegie Science Center's Advanced Materials Award for development of the alloy for this advanced coronary stent.

NETL Earns Two Carnegie Science Awards—NETL's platinum-chromium (Pt-Cr) alloy was selected for the Carnegie Science Center's Advanced Materials Award, which honors "accomplishments in materials science that create new materials or properties leading to significant business, economic, or societal benefits for the region." Development of the alloy began in 2000 when Boston Scientific contacted NETL to partner in the design and production of a new alloy for coronary stents. The new Pt-Cr alloy solved many of the problems associated with traditional stents; it is stronger, thinner, more flexible, and easier to see on x-ray.

In addition, NETL earned a Corporate Innovation Award for its research partnership with regional universities. This award is given to "an organization or representative of an organization that develops and encourages an environment that promotes innovation in science or technology." NETL and its university affiliates combine NETL facilities, expertise, and resources with those of industry partner URS and five nationally known research universities: Carnegie Mellon University, Penn State, the University of Pittsburgh, Virginia Tech, and West Virginia University. Working together, NETL and university partners develop technologies that protect human health and the environment, reduce the energy sector's carbon footprint, find uses for mitigated CO_2, and ensure energy security.

NETL metallurgist Dr. Paul Jablonski was honored to be named a finalist for one of the Partnership for Public Service's prestigious Samuel J. Heyman Service to America Medals—known as the "Sammies." These annual awards pay tribute to federal employees whose work advances the health, safety, and well-being of Americans.

A Beneficial Bounty from Energy Research

Taking NETL Technology to Market

Many common inventions were initially created for another purpose. WD-40, GPS, and Teflon, for example, were originally designed for corrosion prevention of nuclear missiles, military defense, and refrigerant, but they became popular as a slippery solvent, a must-have for civilian travel, and a non-stick surface for your skillet.

NETL, too, has found that its novel ideas can be adapted for other uses. Over the years, many of our technological breakthroughs have been borrowed by other industries for new applications, leading to unexpected benefits. Here are just a few technologies that crossed into other fields.

From Preventing Heavy Metal Poisons to Platinum Recovery

NETL researchers were trying to mitigate heavy metal poisons caused by ground and surface waters reacting with byproducts from mining, manufacturing, and the incineration of waste materials. The best solution was to convert the solid wastes into a glassy product that doesn't react with water, preventing these hazardous liquids from ever forming. The iron and steel industry was already using this "vitrification" process, so NETL researchers borrowed the idea and developed a unique water-cooled, sealed electric arc furnace system to vitrify waste materials.

A few years later, an Engelhard Corporation employee approached NETL about using the arc furnace technology to recover valuable platinum-group metals from catalysts used by the petroleum and transportation industries. A partnership sprang up, and NETL scientists adapted their unique equipment and helped Engelhard develop a high-temperature melting process that economically recovers over 98 percent of the platinum-group metals during processing, leaving very little in the waste material.

From More Robust Digger Teeth to Environmentally Benign Shotgun Shells

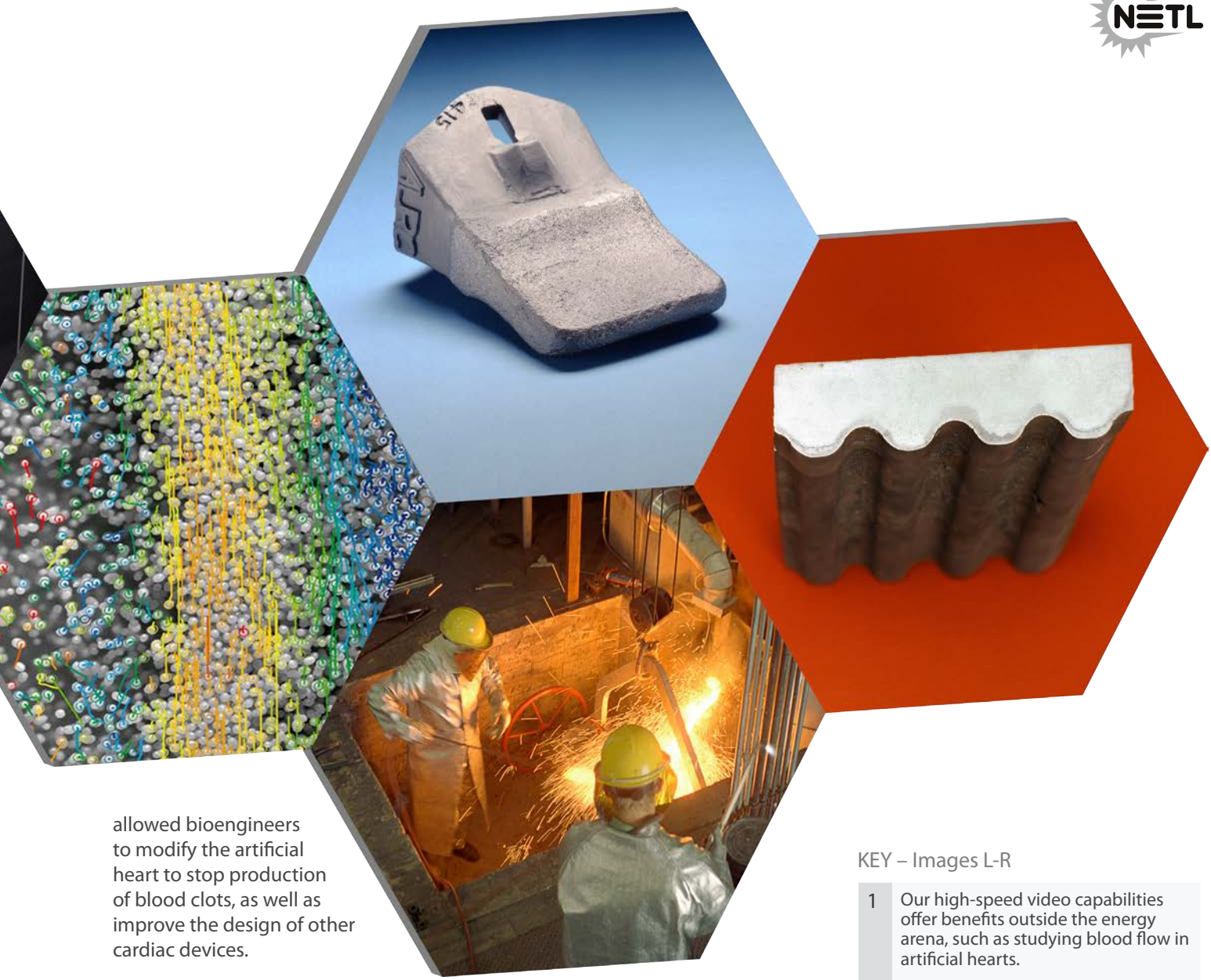
Large-scale mining operations crush and grind enormous amounts of rock to recover valuable minerals. This abrasive process reduces the service life of digging equipment and requires expensive, time-consuming parts replacement. To improve mining equipment's wear resistance, NETL started a project that added extremely hard particles, such as economical tungsten carbide, to the equipment's surface during manufacture.

Years later, NETL engineers were discussing the project with a colleague from a local metal producer who wanted to produce a low-cost, high-density, non-toxic substitute for lead shot in shotgun shells—an idea propelled by the 1980s push for governments to ban lead-containing shells from wetlands and other delicate ecosystems. This new shot would be composed of an environmentally benign iron-tungsten material with a density equal to lead's. However, developers were unsure of how to make spherical shot from this material. One NETL-industry collaboration later, researchers had found a way to make the shot in a process adapted from the one used to coat digger teeth. It was refined for economical commercial production under a new company, Environ-Metal, Inc., resulting in Hevi-Shot™ shotgun shells for use in hunting a wide range of game birds.

From Predicting Movement of Coal Particles to Monitoring Blood Flow

In most advanced energy processes that use coal, the fuel is crushed into coffee-ground-sized particles and then sped through energy systems by air or other gases. Seeing and measuring particle motion in great detail, deep inside fast-moving fields thick with particles is imperative for improving the efficiency and environmental friendliness of coal-based energy production, but doing so was difficult before NETL's high-speed video systems.

With the availability of these systems, NETL was asked by cardiac transplant surgeons at Presbyterian Hospital in Pittsburgh, PA, and Baxter Healthcare to help solve a blood flow problem in an artificial heart. Because blood is a flowing liquid with a high concentration of tiny particles, NETL developed a new high-speed video tool to see and measure blood stagnation in the artificial organ, which was causing blood clots that could eventually dislodge and cause strokes. The data



allowed bioengineers to modify the artificial heart to stop production of blood clots, as well as improve the design of other cardiac devices.

In 2010, we also shared our high-speed video techniques to lessen the impact of the Deepwater Horizon disaster. NETL led a team of elite engineers and scientists that quickly generated the first accurate official estimates of the oil leak rate from the Deepwater Horizon using video of the oil leaks taken by small submarines. NETL's estimate helped responders design a system to permanently cap the well and implement the cleanup effort. For this effort, Secretary of Energy Steven Chu recognized the team with a Secretary of Energy Achievement Award, and the Director of the U.S. Geological Survey presented the team with an award for "Exemplary Service to the Nation."

Hey, Can I Borrow That?

NETL technologies prove to be both novel and versatile. Because so many natural systems have similar attributes, is it any wonder that so much borrowing goes on across different fields of research? Our scientists are proud that their research results can be used to solve problems both inside and outside the energy field.

KEY – Images L-R

1	Our high-speed video capabilities offer benefits outside the energy arena, such as studying blood flow in artificial hearts.
2	NETL's high-speed particle imaging system has been used to track particles in energy, medical, and environmental applications. Imagine trying to watch the movement of each of these particles without it!
3	Equipment coating and shot for hunting derive from similar tungsten-based materials, making them both sturdy and environmentally benign.
4	Platinum group metals are recovered from used catalysts in the electric arc furnace. Then the molten metal is "tapped" in this furnace.
5	This cross section of mining equipment shows the hard surface alloy bonded to the steel.

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